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STANDARD PROCEDURE FOR

TARGET AND BACKGROUND INFRARED MEASUREMENTS

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Office of the Director of Defense Research and Engineering
Washington 25, D. C.

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FOREWORD

This report has been prepared by a panel of scientists who have made measurements of infrared targets and backgrounds. The scientists work in government establishments in Canada, the United Kingdom, and the United States. It is hoped that the methods set forth in this report will be adopted for making and reporting infrared measurements in these countries.

The members of the working panel are:

Chairman: Mr. Charles Ravitsky
Diamond Ordnance Fuze Laboratories

Dr. Cameron Cumming
Canadian Armament Research and Development Establishment

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In its study, the panel has relied heavily on the efforts of the Working Group on Infrared Backgrounds (WGIRB), which has been working on the background problem in the United States since 1954. The group's field of interest now includes targets, atmospheric transmission, and other related aspects of military infrared technology that are intimately related to infrared backgrounds. The WGIRB has already published the following reports:

Proceedings of the Symposium on Infrared Backgrounds, October 1956.

Report of the Working Group on Infrared Backgrounds, "Part One: Aims, Conclusions, and Recommendations on Background Information," July 1957 (IRIA 2359-7-S); and "Part Two: Concepts and Units for the Presentation of Infrared Background Information," November 1956.

Since the publication of the foregoing reports, the WGIRB has been meeting more or less regularly and has in rough draft a new report entitled, Infrared Target and Background Radiometric Measurements, "Part I: Concepts, Units and Techniques." Rough draft copies were made available to this panel, which found the subject matter to be invaluable. The panel believes that this report adequately covers the concepts, units, and techniques of infrared target and background radiometric measurements and recommends that when it is published it be adopted as a standard in the field. It is expected that the Infrared Information and Analysis Center (IRIA) of the University of Michigan will publish this report.

The panel also found the following material useful: the several papers on infrared backgrounds published in the Proceedings of Infrared Information Symposia (IRIS) and the IRIA Annotated Bibliography of Infrared Literature, published by the

Infrared Laboratory of The University of Michigan, the most recent issue being the cumulative issue of February 1961. This bibliography references many reports on infrared target and background measurements, especially those made under United States government contract.

The panel recognizes that many infrared target measurements--often the most valuable ones--will necessarily be highly specific rather than comprehensive. Examples are measurements of potential targets; targets of opportunity, including nonrecurrent or rarely recurrent targets; and targets in situations where measurement is difficult, as well as measurements under programs supported by limited funds. Therefore, the type and method of measurement cannot always be governed by hard and fast rules. For purposeful data, however, the methods set forth in this report should be followed insofar as possible, and as much auxiliary data should be included as is feasible.

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1. RADIATION SOURCES

The separation of radiation sources into targets and backgrounds is to some extent arbitrary and depends on the interests of the observer. For instance, an object on the surface of the sea, which is often a target, may be part of the background in an aircraft-detection problem, while a star may be the target rather than a background radiation source in a navigation system.

1.1 Targets.

1.1.1 Undersea Targets: Submarines.

1.1.2 Static Surface Targets: Static surface targets, such as towns, airfields, power stations, and factories, are very large, are of room temperature or a little higher, and may be difficult to discriminate from the general background. The radiometer for measuring these targets may be airborne.

1.1.3 Mobile Surface Targets: Mobile surface targets, such as ships or tanks, are also of fairly low temperature, but they may have some hotter areas. The motion of such targets against a static background may be an aid to discrimination. Operational detectors will probably be airborne, although ship-to-ship detection is also a possibility, but measurements in the horizontal plane can most easily be made with ground-based or shipborne radiometers. Atmospheric absorption limits the portion of the infrared spectrum that can be used.

1.1.4 Hovering and Very-Low-Flying Aircraft: Operationally, these targets may be detected either from the ground or by airborne equipment. Radiation in the upward hemisphere is thus also important, so measurements will have to be made with both ground and airborne radiometers. Atmospheric absorption limits available wave bands.

1.1.5 Conventional Aircraft: Both ground and airborne measurements are important for these targets. For ground measurements, only the sea-level atmospheric windows are usable. For the airborne measurements, carbon-dioxide absorption is important and ozone may become significant. Since water-vapor absorption will probably be negligible at the higher altitudes, a wide range of wave bands will be usable.

Hot engine metal, exhaust gases with or without reheat, and the kinetically heated skin of supersonic aircraft contribute to the target emissions. For measuring engine and exhaust-gas emissions, PbTe, PbSe, InSb, or Ge/Au detectors are suitable.

1.1.6 Short-Range Missiles: The emission during launching of small, short-range missiles is of interest. Measurements may be required at visible and ultraviolet wave lengths, as well as in the infrared band.

1.1.7 Long-Range Missiles: Large, long-range missiles pose separate problems in the launch, midcourse, and re-entry phases. Measurements made from the ground are restricted by atmospheric absorption; those from high-flying aircraft are affected only by the carbon dioxide and ozone bands; while observations from satellites, for example, will be entirely free from atmospheric absorption.

1.1.8 Satellites: Satellites subtend very small angles at the detector. Thus, theoretically, the desirable high optical gains can be used. Unfortunately, the high satellite velocity would then make tracking extremely difficult.

Measurements may involve either reflected solar radiation or thermal emission. For measuring solar radiation, photoemissive cells are probably the best detectors; whereas for measuring thermal emission relatively long wavelength detectors should be used.

1.2 Background.

1.2.1 Ground: The earth's surface reflects sunlight and skylight both specularly and diffusely. Since the surface includes such dissimilar terrain as ice, snow, the open sea, large and small lakes, as well as the nonuniform ground, data on probable surface conditions are quite important. In addition, the surface radiates as a colored body, and the local temperatures and spectral emissivities of the terrain features determine the magnitude and spectral distribution of the surface.

1.2.2 Atmospheric Gases and Clouds: The atmosphere scatters and attenuates solar and celestial radiation and target radiation. In addition, the atmospheric gases absorb infrared in their well-known absorption bands and also radiate, depending on the local temperature, meteorological conditions, and altitude. The aurorae and airglow also provide a relatively large amount of radiation.

1.2.3 Heavenly Bodies: The sun is the most obvious background source of radiation. The moon, the brighter planets, and the stars also provide background signals, however. These sources of background radiation are becoming more important as the emphasis on ballistic missile interception increases. An additional source of spurious signals may be provided by meteorites whose temporal characteristics may be comparable to those of man-made missiles.

2. MEASUREMENT OF CHARACTERISTICS OF TARGETS, BACKGROUNDS, AND INTERVENING MEDIA

Where possible, targets and background shall be measured separately under controlled conditions. For some types of measurements, however--including the important measurements of potential targets--this may be impossible; then only the contrast between the target and background can be measured as a primary observation.

The intervening atmosphere is a selective absorber and radiator, and its presence in the transmission path modifies the target and background signals. Atmospheric shimmer may seriously interfere with measurements made through viewing paths close to the ground.

3. TARGET CHARACTERISTICS AND METHODS OF MEASUREMENT

3.1 Target Emission

The object of infrared field-radiation measurements, essentially, is to study the dependence of target emission on the various parameters that govern the emission. It is important, therefore, to isolate the main variables in each particular experiment. When conditions are under the control of the observer, the variables shall be measured separately. These parameters are classified, as follows:

(1) Angular distribution about the target
(2) Spatial distribution over the target
(3) Wavelength distribution
(4) Slow time dependence
(5) Modulation

It will be useful at this stage to consider examples of the types of target measurements that fall into these categories. It should be noted, however, that many of the characteristics described in the following paragraphs may interact in the sense that the wavelength distribution may differ for different areas in different directions at different times.

3.1.1 Angular and Spatial Distribution: A typical example involving angular distribution is the measurement of polar-diagram patterns of radiation. In general, a complete polar diagram in the horizontal plane is highly desirable. In addition, the whole of the vertical plane should be measured for airborne targets; and the upper half, for ground targets. For such measurements, the field of view of the radiometer must be large enough to include the total target as viewed from any required direction.

On the other hand, for a study of spatial distribution--such as the emission contours from an extended target--the primary requirement is that the field of view be small and well defined; otherwise resolution will be small in comparison with the scanning time.

In both cases consideration must be given to the wave band to be covered. This can vary from a wide band of wavelengths for spatial study to a very narrow band for the emission from hot gases.

3.1.2 Wavelength Distribution: For the measurement of wavelength distribution, the detector will remain in a fixed position relative to the target. A common example of this type of measurement is the spectral analysis of gas radiation from a jet exhaust. Here care must be taken that the time response of the system is shorter than the rate of change of wavelength. Spectral measurements should be made in two or three preferred directions whenever possible. Absolute data are strongly preferred; if only relative spectral data can be obtained, they should be supported by a simultaneous absolute measurement of total radiation or of radiation in a known wave band.

3.1.3 Slow Time Dependence: Slow variations of emission with time are exemplified by the diurnal change in terrain characteristics or by a rise in the temperature of military targets during their operation.

3.1.4 Modulation: Self-modulation of target radiation is studied less frequently than are the foregoing parameters. The effect would be encountered, however, where radiation is regularly interrupted in or around the source, as by turbine or propeller blades in aircraft engines or by shock waves in rocket-propulsion units.

3.2 Radiometer Design.

Infrared radiometers used for field measurements consist, generally, of the following parts:

(1) An infrared-sensitive element
(2) Wavelength filters
(3) An optical system
(4) A radiation modulator or chopper
(5) Electronic amplifiers and indicators

Although it is convenient to discuss these items separately, they are of course interrelated. In selecting or designing any part of the system, one must bear in mind the over-all requirement of the experiment as outlined in section 3.1; if possible, a reasonable estimate of the target characteristics should be made before the apparatus is designed.

3.2.1 Infrared-Sensitive Element: The elements most commonly used give changes of electrical characteristics with incident radiation and are either quantum detectors such as photoconductors or thermal detectors such as thermopiles and bolometers. Certain infrared cells use changes in physical properties, such as pressure or surface tension, but these are less common in field measurement and will not be considered here.

The choice of cell is dependent mainly on the wavelength response, sensitivity, and time constant. The quantum detectors usually have short response times and high sensitivities, but they operate only in restricted wave bands. In some cases, especially for longer wavelengths, these cells require cooling to attain the necessary sensitivity. Thermal detectors, on the other hand, respond over wide wave bands with moderate sensitivity and relatively long time constants.

3.2.2 Wavelength Filters: Apart from the limitations imposed by the type of cell being used, the nature of the measurement may demand further wavelength restrictions. In the extreme case where the wavelength dependence of the radiation is the chief parameter to be studied, a spectrometer must be used. If, however, integrated radiation within a certain band is required--e.g., jet-exhaust-gas radiation --then limiting filters can be used. Such filters can be constructed from various materials that have fairly well-defined cutoff or cut-on wavelengths. Narrow-band interference filters can also be used.

Filters are also widely used to reject radiation from troublesome backgrounds whose spectral characteristics differ from those of the target. A common example is the exclusion of most of the reflected sunlight when the target temperature is only a few hundred degrees.

3.2.3 Optical System: The design of the optical system is influenced by the requirements for both optical gain and field of view. Systems usually employ

reflecting optics of the Newtonian or Cassegrainian type, comprising a concave collecting mirror with a secondary plane or convex mirror. Alternatively, a converging lens may be used as the collector; but in this case both the available diameter and wave band are restricted, and the focal length of the lens will show wavelength dependence.

For a simple radiometer, the target radiation could be imaged directly onto the infrared-sensitive element or transmitted to it through an internally reflecting light pipe. Detectors, however, are seldom uniform in sensitivity across their entire area. To overcome this defect, a field lens can be placed close to the focal plane to image the collector onto the cell element so that the same part of the cell is always used and the radiometer, therefore, has a flat response over the full field of view. With this arrangement sighting errors are minimized and the radiation from an extended target is uniformly effective.

It is usual in such a system to place a limiting aperture in or near the focal plane to control the field of view, which then depends on the focal length of the system and the aperture size.

In order to obtain a system giving the maximum field of view, other features need to be considered. When a field lens is used, these are the lens itself, the size of the sensitive-cell area, and the diameter of the collecting mirror. It can be shown that, assuming a constant f number for the lens, the field of view is proportional to cell diameter and inversely proportional to mirror diameter. The requirements for large fields of view therefore oppose those for high radiometer sensitivity.

3.2.4 Radiation Modulator or Chopper: Since the change in cell characteristics with radiation is small, it is generally convenient to modulate the incident radiation so that a.c. electronic amplifiers can be used. One of the most common forms of modulation is produced by mechanically interrupting or chopping the radiation. This can be done conveniently near the focal plane of the collecting system--close to the limiting aperture and immediately before the cell and associated components, such as filters or the field lens.

The chopper can consist of either regularly spaced blades to produce amplitude modulation or variably spaced blades to give frequency modulation. Similar effects can also be obtained by having fixed reticles of these shapes and rotating the collecting mirror to scan the incoming beam of radiation over the reticle. The type of modulation considered here will be that produced by a symmetrical rotating chopper, since this is probably the system most commonly used for this type of measurement.

At this stage, the size of the chopper blade or gap relative to the limiting aperture should be considered briefly. If both the chopping blade and gap are as large as or larger than the aperture, then the full field of view of the radiometer will be modulated. This method gives a well-defined field of view suitable for spatial discrimination of extended targets or backgrounds. An efficient radiometer for such a measurement could have a controlled reference black body whose radiation is compared to the received radiation by reflection from a polished chopper.

If, however, radiation from the whole target is to be measured in the presence of troublesome background radiation, the background radiation may be minimized if the aperture is made exactly equal in size to an integral multiple of a chopper blade

plus gap so that, in effect, the background remains unmodulated. A fine control of the aperture size can be advantageous. In this case, it is desirable to make the chopper blades nonreflecting; otherwise, reflections of cooled cells and their surroundings are contrasted with warmer backgrounds as the chopper rotates.

The waveform produced by chopping must also be considered. When the target image is appreciably smaller than the chopper-blade width and the cell response is shorter than the chopping frequency, the resulting waveform from the cell is approximately square and contains the maximum amplitude of the fundamental of the chopping frequency. When the size of the target image is comparable with the blade width, the amplitude at the chopping frequency is smaller, although the image may still be interrupted completely by the chopper. It will be realized that with this type of chopping system the radiometer has both a total and an instantaneous field of view--the former corresponding to the size of the total aperture in the image plane, the latter fixed by the size of the gap between the chopper blades.

3.2.5 Electronic Amplifiers and Indicators: In the type of instrument described, the cell output can be amplified by conventional electronic amplifiers tuned to peak at the modulation frequency. Care must be taken to ensure that both the amplifier bandwidth and indicator time constant are adequate to follow the most rapid signal variations that occur. The amplifiers should also be designed to have a minimum noise level. The monitoring of the cell operating conditions (e.g., current, applied voltage, temperature) during the measurements is advisable.

3.3 Use and Calibration of Radiometers.

All radiometers shall be calibrated so that the results obtained for target emissions can be presented in absolute units independent of the type of instrument used. It is, therefore, necessary to obtain the detector response to a known quantity of radiation. There are, however, several differences between the characteristics of the target and of the calibration source. Of these, the following may be important and are discussed below:

(1) Spectral emissions
(2) Intervening paths
(3) Image sizes
(4) Radiation strengths

3.3.1 Spectral Emissions: A common method of calibrating the radiometer is to use a black-body oven of known temperature and radiating aperture. Normally the oven temperature will be chosen so that the emission from the oven covers the full wave band of the detector. This procedure, combined with the spectral response of the radiometer, provides a precise calibration. For routine field calibrations, it is often adequate to approximate the spectral sensitivity curve by an effective spectral band. Detailed numerical integration is then unnecessary, and a radiation slide rule gives an immediate calibration. If, however, the target radiation is very unlike a black-body distribution, this second method of calibration is no longer valid, and a detailed calibration is required for small wavelength intervals over the total band, together with the spectral emission of the target.

3.3.2 Intervening Paths: Radiation losses that occur in the relatively short calibration-path length can be allowed for by taking the detector wave band to include this atmospheric path. In the extra range to the actual field target appreciable

transmission losses may occur. The target radiation (1) can be given as the effective emission as seen through a given atmospheric path or (2) a correction can be made for absorption. For many types of measurements sufficient data on atmospheric transmission exist to permit correction without a special investigation.

3.3.3 Image Size: Differences in size of the target and calibrating-source images in the chopper plane result in different output waveforms from the infrared cell and in corresponding changes in detector sensitivity. This effect should be studied for the particular radiometer. It is often found in practice that as long as the image size is less than about two-thirds of the blade width the error is not serious for amplification at the fundamental of the chopping frequency. This effect, however, may cause a further possible error if the image of the oven is defocused at the short ranges generally used during calibration. This error can be allowed for when the detector sensitivity is calculated, or it can be eliminated by use of a parallel beam of calibrating radiation or by chopping the radiation at the oven. Such source chopping has the added advantage that backgrounds remain unmodulated.

It is assumed that most radiometers have a fairly uniform response over the full limiting aperture or field of view, as would be the case with a correctly placed field lens. If a radiometer does not have such a uniform response, then further corrections need to be applied according to the sighting of the detector or when the total radiation from large targets is measured.

3.3.4 Radiation Strengths: A further point to be considered when the detector response is compared to calibration and target signals is that the detector response should be linear with incident radiation or that any deviation therefrom should be known. With strong radiation, the system may possibly become overloaded. On the other hand, weak signals may become merged with background or system noise.

For measurements made under conditions of low signal-to-noise ratio, the data reported shall be corrected for the effects of the noise. It is especially important for the estimated accuracy of the reported data to be included for such low-signal-level situations.

If the measurement conditions are entirely under the control of the observer, they can be adjusted in several ways to optimize the experimental accuracy. Background radiation should be minimized, and it should be selected to have characteristics as different as possible from those of the targets. For example, if the target is an extended horizontal target (such as a jet plume), then a chopper with long thin blades (which move effectively in the vertical plane as seen by the target) may be used. A background free of horizontal striations should then be chosen.

For night measurements of nonluminous targets, indicator lamps placed on the targets are useful aids for sighting. For radiometers working at wavelengths beyond the edge of germanium filters (i.e., longer than 1.9 microns), which is generally the case, small lamps covered by thick ($\frac{1}{2}$ to 1 inch) Perspex (lucite) are convenient since they have negligible emission beyond 1.8 microns.

3.4 Reflection.

In many applications, such as daylight measurements of approaching aircraft, the sunlight reflected from the target may provide a much larger signal than would result from its own infrared emission. For such applications, data should be

obtained for the relative proportions of specular and diffuse reflection as a function of the angle of incidence of the radiation. Because of the complex surfaces of targets, the polar diagrams of the reflectivity depend strongly on the angle of incidence. To obtain useful data, the targets should be measured under operational conditions; that is, daytime measurements should be made with the sun at various zenith angles and nighttime data on target detection by reflected light should be obtained with various searchlight target aspects.

For target trajectories where the target aspect with respect to either the radiation source or the observer changes with time, the target signal will also change, varying with the effective cross section of the target as a specular and diffuse reflector.

The surface finish of the target will greatly modify the magnitude and spectral distribution of the reflected radiation. Thus, the World War II night fighters when freshly painted had very low reflectivities.

An additional feature of the radiation reflected from propeller-driven aircraft is the characteristic modulation at the rate at which the propeller blades rotate. This modulation can be quite useful in identifying such targets.

3.5 Obscuration.

Because targets are rarely transparent, they obscure that portion of the background that is beyond them. This obscuration causes a decrease in the received radiation whose spectral characteristics are those of the background but whose angular size and apparent motion depend on the target. For optimum detection of such obscuration signals the detecting system should be matched to the spectral characteristics of the background. Identification of the target depends on the temporal characteristics of the obscuration signal. Obviously, the size of the signal (1) increases as the target range decreases and (2) varies as the apparent obscuration cross section of the target changes. An additional obscuration characteristic is that caused by the contrail of a high-altitude aircraft to the extent that the contrail obscures its background.

3.6 Secondary Targets or Transposed Characteristics.

Examples of secondary targets are contrails or ionized air around a missile re-entering the earth's atmosphere. In general, the characteristics of these targets will differ from those of the actual targets. In addition, these secondary targets will be displaced in space and/or time from the target to be measured.

4. BACKGROUND CHARACTERISTICS

A fundamental difference between targets and backgrounds is that the radiation from background may be independent of range, i.e., the observer sees only an angular distribution of incoming radiation. Usually any solid background is so far away that it is separated from the observer by a thick atmosphere that emits and absorbs. In some cases--for example, a sky--the background can be solely atmosphere.

The background is itself at a temperature above absolute zero and will therefore radiate. As seen by the observer, the most obvious characteristic of the background is its angular distribution. For backgrounds with definable ranges, an areal distribution can be deduced.

The radiation from the background is a function of wavelength. Typical backgrounds are terrestrial, which approach gray bodies, and atmospheric, which in addition may have sharp line spectra. Backgrounds vary widely over the surface of the earth and in the atmosphere. They can change drastically with the weather and may have very sharp boundaries--as, for example, the aurorae and meteorites. Beyond the atmosphere are the heavenly bodies whose self-emission may be dominant --as for the sun and the stars--or secondary to their reflection of sunlight--as for the moon, Mars, meteors, and man-made missiles. The observer may not always be able to distinguish between the self-emission of the background and scattered or reflected sunlight.

Temporal variations of the background range from slow seasonal changes to rapid statistical fluctuations in the radiation flux reaching the radiometer. Movement by either the observer or the background will generate transient modulation that can be analyzed as a frequency spectrum.

As noted in section 3.5, the obscuration of the background radiation may be a target signal.

Methods for analyzing and presenting background data have been investigated exhaustively by the Working Group on Infrared Backgrounds. It is recommended that workers in infrared obtain copies of this report.[1]

5. INTERACTION OF TARGETS AND BACKGROUNDS OR CONTRAST DETECTION

In some measurements, particularly those made under operational conditions, the primary measurement may be the contrast between the target and background. If the target is moving, its detection is relatively straightforward. If it is fixed, its detection is more difficult, but several methods described permit fixed-target detection.

In general, contrast detection is the desired quantity only if one will always be interested in a particular target as seen against a particular background.

5.1 Field Chopper Discrimination.

Frequently the target to be investigated will have an angular subtense appreciably smaller than the smallest graininess of the background. For measurement, such targets can be discriminated by so placing a chopper at the focus of the target that the detector always sees the same proportion of the background and chopper.

5.2 Spatial Variation.

The measurement instrument can be scanned in angle over the target and adjacent background. Such a measurement is most informative for a fairly uniform background.

[1]IRIA 2359-7-S, cited in Foreword.

5.3 Temporal Variation.

If the target is moving, the change in the atmospheric path may change the spectral distribution of the received target radiation, and the change in intensity will then be even greater than that stated in the inverse-square law. Since the background will stay constant (except for fluctuations), the change in target radiation is an additional target detection technique.

6. INTERVENING MEDIA

The properties of the medium between the target and the measuring instrument affect the calculation of target or background radiance from the irradiance measured at a distant instrument. In infrared target or background measurements, the medium of concern is almost always the atmosphere. The atmosphere--a heterogeneous mixture of permanent gases; water in the form of vapor, cloud, or fog; and a wide variety of solid particles--can influence any measurement made through it because it can absorb or scatter radiation and introduce scintillation.

6.1 Absorption.

In a medium, absorption is that attenuation of radiation by a molecule of the medium which leaves the molecule in a different quantum state. Kirchhoff pointed out that a substance that emits radiation can also absorb it; consequently, the absorption of a medium is characterized by a banded structure similar to its emission spectrum. The absorption spectrum of the total atmosphere has been studied by observations of the solar spectrum; measurements of atmospheric absorption for horizontal sea-level paths are also available. Data for the atmospheric absorption (or transmission) for slant paths or for high-altitude paths are less extensive.

6.1.1 Calculation of Atmospheric Absorption as it Affects Target Measurements: Theoretical calculations of the absorption of infrared radiation in a rotation-vibration band or a pure rotation band can be carried out only after certain simplifying assumptions have been made; consequently, the precision of the calculations is degraded. A better procedure for calculating transmission through a horizontal path is based on laboratory measurements of the transmission and empirical formulae derived therefrom. Extensive data of this type for various constant-pressure paths are available for carbon dioxide and water vapor. The correct procedure for treating slant atmospheric paths in which the total pressure is variable is still under dispute.

It should be stressed that atmospheric absorption is a particularly critical parameter in the measurement of targets consisting of hot gaseous plumes when the emitting molecular species have chemical bonds identical with those found in the atmosphere.

6.1.2 Influence of Atmospheric Transmission on Background Measurements: The atmospheric background extends right up to the measuring instrument. Absorption within the instrument itself (for example, between a chopper and a detector) may also be important.

6.2 Scattering.

If the atmosphere were purely gaseous the attenuation of radiation in the optical regions could be corrected for on the basis of the molecular scattering theory. This attenuation is a function of the index of refraction, the density, and the depolarization factor--all known quantities--and has a wavelength dependency approximately proportional to λ^{-4}. Except for measurements in the visible and near-ultraviolet regions through the cleanest air, however, scattering losses caused by particles suspended in the atmosphere are much more important.

The atmospheric aerosol consists primarily of three types of particles:

(1) small particles (less than 1 micron) of salt water, which may be liquid and spherical or crystalline and irregular,

(2) large droplets (1 to 100 microns) of water,

(3) solid dust particles.

Of these particles, those described under (1) are largely responsible for atmospheric haze; those under (2) are characteristic of clouds and fogs; and those under (3) are found in industrial areas, volcanic and desert regions, and after forest fires.

If the size and number of particles and their refractive index are defined, the attenuation as a function of wavelength may be calculated. In the absence of these data, little can be done from a theoretical point of view, since the wavelength dependence of the attenuation varies markedly with the size of the particles.

Meteorological observations are regularly made to determine visibility. The typical meteorological observation has some use but will not suffice for precise measurements of attenuation because it is a very subjective observation and the visual range in the visible region is not a reliable indication of attenuation in other spectral regions.

The panel recommends that the scattering coefficient or the extinction coefficient rather than the visual range be measured by meteorological observers. Scattering coefficients for the infrared region are not known for clouds, and data on the attenuation of infrared radiation through cloud formations at high altitudes are urgently needed.

6.3 Scintillation.

Temporal and spatial fluctions in the refractive index of the atmosphere are responsible for the phenomenon known variously as scintillation, shimmer, and twinkle. It can be expected that an observation of the state of scintillation for a given path made in any wavelength region (e.g., visible) will be a reliable measure of the scintillation for that path in the entire optical region.

The severe turbulence in the immediate neighborhood of such targets as jet exhausts can be thought of as scintillation; this phenomenon may be important but is more properly thought of as a property of the target.

7. AUXILIARY MEASUREMENTS AND DATA

In addition to the infrared observations, various auxiliary measurements shall be made.

7.1 General Data.

General data to be included are the date and local standard time of the observation and the position of the sun with respect to the target.

7.2 Meteorological Measurements.

With respect to meteorological measurements:

(1) The following data shall be reported for the environments both of the measuring instrument and of the target, when possible:

- (a) Temperature, pressure, wind velocity, and
- (b) Absolute humidity, precipitation, visual extinction, cloud condition.

(2) The condition of the ground and/or sea will be reported.

(3) In reporting on high-altitude targets, backgrounds, and transmission measurements, a vertical profile through the atmosphere shall be included when it is available.

7.3 Geometrical Measurements.

The geometry of any target and measuring instrument, including target attitude and altitude and the slant range and altitude of the radiometer, shall be specified as completely as possible.

7.4 Auxiliary Target Specifications.

All relevant available target data shall be given, for example:

(1) Engine type and such apparatus as a JATO, afterburner, etc.
(2) Power level
(3) Fuel type and consumption
(4) Surface temperature of the target and environment

8. UNITS AND SYMBOLS

The following set of symbols shall be used for the radiometric quantities[2]:

Symbol	Name	Description	Unit
U	Radiant energy		Joule
u	Radiant energy density		Joule cm^{-3}
P	Radiant power	Rate of transfer of radiant energy	Watt
W	Radiant emittance	Radiant power per unit area emitted from a surface	Watt cm^{-2}
H	Irradiance	Radiant power per unit area incident upon a surface	Watt cm^{-2}
J	Radiant intensity	Radiant power per unit solid angle from a source	Watt $ster^{-1}$
N	Radiance	Radiant power per unit solid angle per unit area from a source	Watt $ster^{-1}$ cm^{-2}
P_λ	Spectral radiant power	Radiant power per unit wavelength interval	Watt $micron^{-1}$
W_λ	Spectral radiant emittance	Radiant emittance per unit wavelength interval	Watt cm^{-2} $micron^{-1}$
H_λ	Spectral irradiance	Irradiance per unit wavelength interval	Watt cm^{-2} $micron^{-1}$
J_λ	Spectral radiant intensity	Radiant intensity per unit wavelength interval	Watt $ster^{-1}$ $micron^{-1}$
N_λ	Spectral radiance	Radiance per unit wavelength interval	Watt $ster^{-1}$ cm^{-2} $micron^{-1}$
ϵ	Radiant emissivity	Ratio of "emitted" radiant power to the radiant power from a black body at the same temperature	--
α	Radiant absorption	Ratio of "absorbed" radiant power to incident radiant power	--
ρ	Radiant reflectance	Ratio of "reflected" radiant power to incident radiant power	--

[2]This set of units and symbols, taken from the WGIRB report, has since been published in the September 1959 issue of Proceedings of the IRE. It is suggested that a copy of this issue be obtained by all workers in infrared.

Symbol	Name	Description	Unit
τ	Radiant transmittance	Ratio of "transmitted" radiant power to incident radiant power	--
λ	Wavelength	--	micron

$1\,\mu = 1/10^{4}$ cm $= 10^{4}$ Å

The expression of radiometric quantities in quanta or photons rather than watts may be preferable in certain instances, particularly when a radiometer has uniform photon response over a wide spectral range or when fluctuations in the photon stream reaching the detector are important. The following two units will be used, as on the Makowski Radiation Slide Rule:

Symbol	Name	Description	Unit
Q	Radiant photon emittance	Number of photons per second per unit area emitted from a surface	photon sec^{-1} cm^{-2}
Q_λ	Spectral radiant photon emittance	Radiant photon emittance per unit wavelength interval	photon sec^{-1} cm^{-2} $micron^{-1}$

9. PRESENTATION OF DATA

9.1 Reduced and Primary Data.

The main publication shall contain suitably reduced data, but primary measurement data shall be available in appendices or on request. Because of the uncertainty in any correction for atmospheric attenuation, the "apparent" radiant intensities (i.e., uncorrected for atmospheric attenuation) shall also be given.

9.2 Graphical Data Preferred.

Graphical data are preferred to tabular data, and graphical scales shall be in absolute units, if possible. Polar plots shall be used for angular distributions.

9.3 Units of Measurement.

Measurements shall be reported in metric (centimeter-gram-second) units and degrees Kelvin. The rarer prefixes to these units should be avoided; for example, measurements of length should be given only in kilometers, meters, centimeters, or millimeters. Wavelengths shall be in microns, and fuel quantities shall be in kilograms.

"Homely" units may be used in summaries and conclusions, although units that differ from country to country (for example, gallons or tons) will not be used. With the unit "miles," show whether nautical, etc., as appropriate.